Modeling Material Processes with Moving Interfaces

An optimizing tool for welding, crystal growth, and electron-beam vaporization

With the MELT computer code, we can calculate the material and energy flow in material processes involving moving phase boundaries. Complex interactions exist between solid, liquid, and vapor phases in many important industrial systems. If we can understand these phenomena, we can assist process optimization.

Finite-element methods for moving phase boundaries

It is important to track the locations of interfaces because the transport properties of solid, liquid, and vapor phases differ greatly. If we know the interface locations, we can assign the appropriate modeling equations to specific phases. The effects of viscosity, for example, are included in the liquid phase but not in the solid phase.

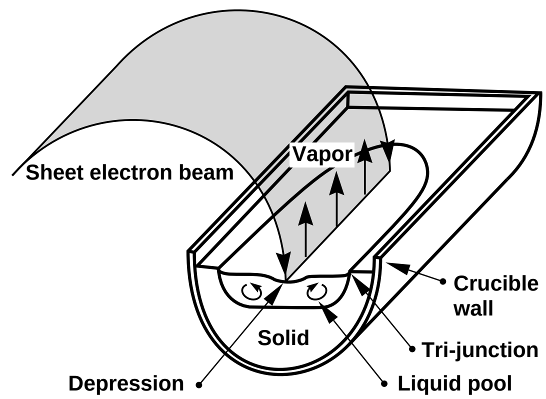
As part of our finite-element strategy for tracking interfaces, we use meshes (arrays of points at which the solution is found) that deform as the phase boundaries move. Mesh points are kept on the interface as it moves. Interior points remain smoothly distributed within a material phase. At each iteration, or time step, robust implicit methods are used to calculate grid-point locations simultaneously with field variables such as velocity and temperature.

APPLICATIONS

- *Welding*
- *Crystal growth*
- *Continuous casting*
- *Electron-beam vaporization*
- *Electron-beam cold-hearth refining*

Electron-beam vaporization

We use the MELT program to model the material and energy flow in an electron-beam vaporizer for aluminum. The energy from an electron beam heats an aluminum ingot confined in a water-cooled crucible (see the accompanying figure). A portion of the beam energy is used to vaporize the aluminum. Another fraction is lost to thermal radiation and the formation of secondary electrons. The balance is transported by convection and conduction to the crucible. Near the beam impact site, liquid metal circulates in a pool bounded by its own solid.



Optimal design of welding processes modeled as a function of beam and material parameters.

Two-dimensional, steady-state calculations show that buoyancy forces drive surface liquid away from the beam impact area. In addition, the high-flow intensity leads to the formation of several flow “cells.” The pool-boundary location is strongly coupled to the flow of material and energy. Thermal convection contributes to a shallow pool, and the thrust from the departing vapor creates a depression in the liquid–vapor interface. Inclusion of these effects is important in developing an accurate model.

The finite-element method is also being applied to continuous casting. It is well-suited to other material processes with moving interfaces, such as welding and crystal growth. Finite-element modeling can be used as a design tool to optimize performance as a function of process and material parameters.

Availability: MELT, our powerful modeling tool, is available now. We are seeking industrial partners with whom we can tailor our model to solve specific problems.

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